

1 **A bibliometric analysis of Soil remediation Based on Massive research literature data During**
2 **1988-2018**

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16 Short title: Bibliometric analysis of Soil remediation During 1988-2018

17

18 **Abstract**

19 Soil is an important part of the ecosystem with significant roles that help human population sustain.
20 Research on prevention and remediation of soil pollution has been carried out when 1985. This study
21 analyzed the 1988–2018 soil remediation dataset in the Web of Science database by bibliometric
22 methods to illustrate the current research trends and hot topics of quantitative analysis and soil
23 remediation in the world. To further identify the major soil contamination topics, we employed
24 social network analysis. The results indicate that the field of soil remediation has entered a stage of
25 rapid progress. The United States has a strong overall strength with the largest number of published
26 articles and larger impact. China ranks second. We identified Journal of hazardous materials as the
27 most influential journal and Chinese academy of sciences as the most influential institution.
28 Academic cooperation showed an increasing trend at the author, institutional, and national levels
29 with an average level of cooperation of 3.57, 1.66, and 1.16, respectively. However, the growth rate
30 of cooperation at the national level is relatively low. In addition, the frequency and co-word analyses
31 of keywords revealed the important research topics. “heavy metals” , “PAH”,
32 “bioremediation” ,“Phytoremediation” and “Electrokinetic remediation” were identified as the hot
33 topics. The findings of this study will help researchers understand the status of soil remediation as
34 well as provide guidance for future research.

35

36 **Introduction**

37 Soil is an important dependence of human survival. contaminated soil which polluted by heavy
38 metals, agricultural inputs and solid waste, deteriorates the environment and restricts human
39 development[1-3]. Soil contamination and remediation are global problems that have attracted the
40 attention of governments and researchers[4]. In order to protect soil and prevent further deterioration,
41 various studies have been conducted on remediation of contaminated soil. Many soil remediation
42 technologies have been developed during the past few decades on different aspects such as
43 chemistry, biology, agroecology, and electrodynamics[5,6]. During this period, new research ideas,
44 methods, and means were introduced, and the remediation technology system was improved. At the
45 same time, the intersection of discipline such as soil, engineering, chemistry and new materials
46 promoted the rapid progress in soil remediation research[7]. However, the future of soil remediation
47 technologies is uncertain and the need for multidisciplinary research is high. To gain research
48 progress in soil remediation, we should focus on the key processes in soil remediation and break
49 through the bottlenecks. We should explore new remediation technologies and perform a
50 quantitative analysis of the relevant information in the field.

51 Bibliometrics can explores structures, characteristics, and laws of science and technology [8]. We
52 used bibliometric method to analyze current research and the development trends in the field of soil
53 remediation including total number of articles, countries' performances, productive journals,
54 performances of authors and institutios, citation, and extent of academic collaboration. This work
55 will fill the gap in the field of soil remediation. Using frequency analysis and co-occurrence analysis
56 of high-frequency keywords will help other researchers grasp the essence of advanced topics in this

57 field. Based on the analysis, potential limitations and directions were derived to provide guidance to
58 plan and implement future research.

59

60 **Materials and methods**

61 **Data source**

62 Data used in this study were taken from the Web of Science (WOS) core collection including
63 Science Citation Index Expanded, Social Sciences Citation Index, Conference Proceedings Citation
64 Index-Science, Conference Proceedings Citation Index-Social Science & Humanities, and Emerging
65 Sources Citation Index. We searched the title, abstract, and keywords of 13891 published articles
66 using 1988–2018 as the time phase, “soil remediation” as the keyword, and “subject” as the field.

67 The search date is January 18, 2019. The WOS derived document records included titles, authors,
68 abstracts, and keywords. These indicators were analyzed using BibExcel, Ucinet and VOSviewer.

69 A general statistical analysis was performed on national distribution, journals, topics, authors,
70 institutions, and citations. In addition, impact factor, academic cooperation, and national
71 comprehensive strength were used to reflect the current academic impact of a country and of an
72 author. Research and development in the field of soil remediation was analyzed, which will help
73 researchers and policy makers attain an overall understanding of the subject.

74

75 **Impact factor**

76 As the most commonly used assessment tool in bibliometrics, impact factor helps assess the merit of
77 journals, authors, institutions, and countries [9]. We collected the impact factors from the ISI Journal
78 Citation Reports to evaluate the quality of the journals.

79

80 **Academic cooperation**

81 Cooperation in scientific research is improving at all levels and in all areas, and this is a common
82 indicator to measure closeness of collaboration in scientific research [10]. The indicators at all levels
83 (author, institution, and nation) were used to calculate the degree of academic cooperation in the
84 field of soil remediation. Equations used for calculation are as follows:

85 (1) Author cooperation:
$$G_A = \frac{\sum_{i=1}^N \alpha_i}{N}$$

86 (2) Institutional cooperation:
$$G_I = \frac{\sum_{i=1}^N \beta_i}{N}$$

87 (3) National cooperation:
$$G_C = \frac{\sum_{i=1}^N \gamma_i}{N}$$

88 Where, G_A , G_I , and G_C represent the degree of cooperation by author, institution, and country,
89 respectively; α_i , β_i , and γ_i represent the number of authors, institutions, and countries contributing to
90 each paper, respectively; N represents the total number of articles in the field.

91

92 **Academic scale**

93 Academic influence and academic competitiveness reflect a country's comprehensive research
94 strength. Four indicators were selected to assess national comprehensive research strength: (1) total
95 number of articles (2) total citations (3) number of authors, and (4) number of research institutions.
96 By calculating the standard scores of these four indicators, the combined score of each country was
97 obtained, and the formulae used for calculation are as follows:

$$98 \quad (4) \text{ Standard score: } T_{ij} = \frac{x_{ij} - \bar{x}_{ij}}{\sqrt{\sum_j (x_{ij} - \bar{x}_j)^2}} + 1$$

$$99 \quad (5) \text{ Comprehensive score: } T_i = \sum_j T_{ij}$$

100 Where, T_{ij} represents the standard score of indicator j in country i ; x_{ij} represents the original
101 score of indicator j in country i ; \bar{x}_{ij} represents its average score; T_i represents the sum of the standard
102 scores in country i ; and M represents the number of countries.

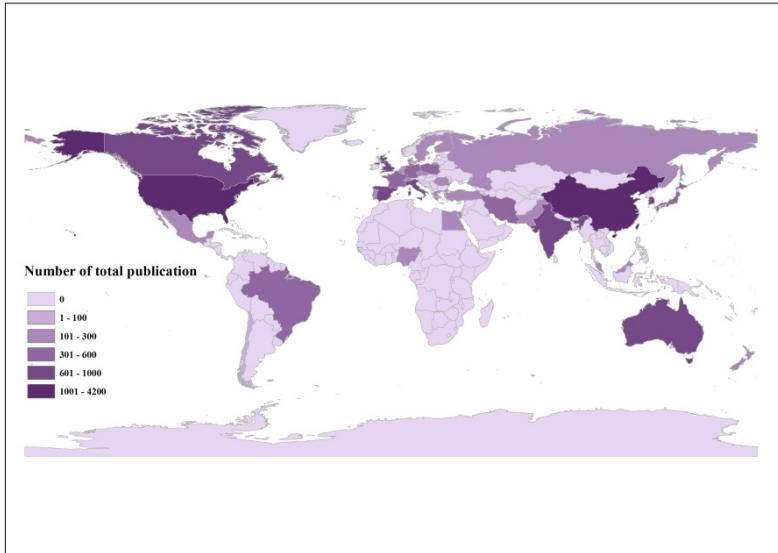
103

104 **Results**

105 **Contribution of country**

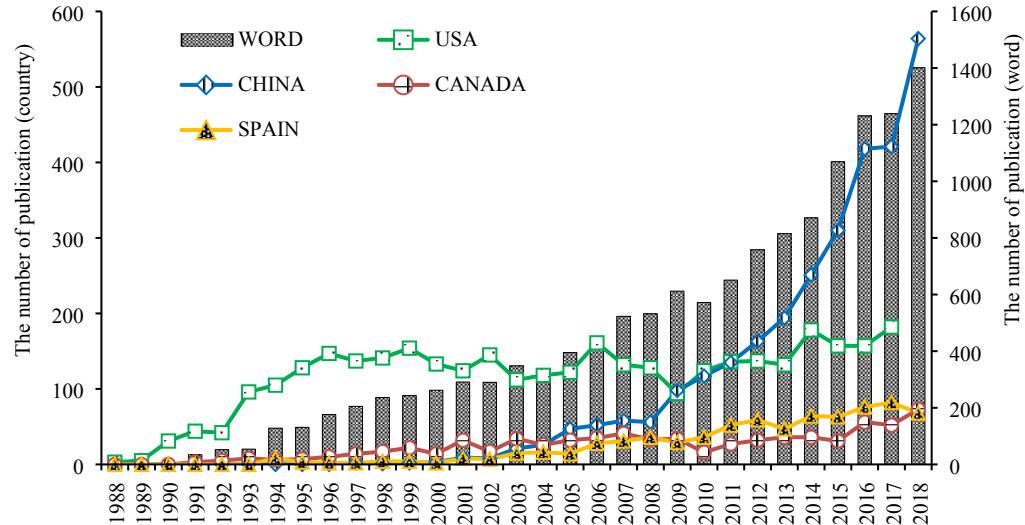
106 The number of articles in a specific area is an important indicator to assess development trend.
107 Analysis revealed that a total of 13,891 journal articles were retrieved from 148 countries and
108 regions including England, Scotland, Wales, and Northern Ireland; China included only mainland
109 China, and Hong Kong, Macao, and Taiwan were analyzed as separate regions. Different colors
110 represent the number of articles in different geographical regions(**Fig 1**), the darker the color, the

111 more the number of articles. The articles on soil remediation were mainly from the United States,
112 China, Spain, and Canada. Research in this field was also prominent in Korea, Italy, and Australia.



113
114 **Figure 1** World map showing the distribution of research articles

115 The number of articles in the soil remediation field has grown rapidly over time (**Fig 2**), and the
116 growth happened in three phases. Only a few developed countries such as the United States and
117 Canada published few articles in the early beginning phase (1988 to 1998). In order to improve the
118 quality of cultivated soil, healthy human living environment, many countries began to pay attention
119 and study soil issues in the stable development phase (1998 to 2008) . China's soil remediation
120 research is developing rapidly in the rapid growth phase (2008 to 2018).



121
122 **Figure 2 Distribution of major publishing countries**

123
124 **Productive institutions**

125 6637 institutions contributed to the soil remediation field. Among developing countries, four
126 institutions among the 10 most published research institutions were in China (**Table 1**), the Chinese
127 Academy of Sciences and the University of Chinese Academy of Sciences ranked first and third.
128 Other research institutions were from developed countries, four from the United States and two from
129 France. The Chinese Academy of Sciences contributed 706 articles (56.54% of the total number of
130 Chinese articles). This indicates that Chinese Academy of Sciences is in a leading position in the
131 field of soil remediation.

132 **Table 1 Productive institutions during 1988-2018.**

RANK	Institution	Country	TP	TPRW(%)
1	Chinese Academy of Sciences	China	706	5.1
2	United states department of energy doe	USA	369	2.7
3	University of chinese academy of sciences	China	234	1.7
4	Centre national de la recherche scientifique	France	230	1.7
5	Consejo Superior de Investigaciones Cientificas	France	227	1.6
6	university of california system	USA	206	1.5
7	Institute of soil science	China	204	1.5

8	Zhejiang University	China	179	1.3
9	United states department of agriculture	USA	177	1.3
10	State University System of Florida	USA	175	1.3

133 Note: TP is the number of total articles; TPRW(%) is the ratio of the number of journal's
134 publications in which institution to the total number of articles.

135

136 **Productive authors**

137 32534 authors contributed to the soil remediation field. The authors with the most recent articles
138 were from Denmark, and the productive authors were from other developed countries such as South
139 Korea, United States, Australia, and Spain among the top 10 authors in the field of soil
140 remediation(**Table 2**).

141 **Table 2 Productive authors during 1988-2018.**

Rank	Authors	Country	TP	TC	CPP
1	Ottosen LM	Denmark	82	1574	19.2
2	Beak K	Korea	70	1091	15.59
3	Reedy KR	USA	70	2347	33.53
4	Naidu R	Australia	66	1032	15.64
5	Canizares P	Spain	59	766	13.15
6	Rodrigo MA	Spain	59	736	12.47
7	Tsang DCW	Hong Kong	57	981	11.21
8	Luo YM	China	56	1173	20.95
9	Lestan D	Slovenia	52	1485	28.56
10	OK YS	Korea	52	1732	33.31

142 Note: TP is the number of total articles; TC is the number of total citations; CPP is citations per
143 publication.

144 The most productive author was Ottosen LM (Denmark) has contributed to 82 articles. He mainly
145 studied the use of electrodialysis technology and the use of electricity to deal with copper, lead, zinc,
146 and chromium in industrial and mining fields [11,12]. Reddy K R (United States) was the highest

147 cited author, whose articles has been cited 2347 times and mainly about electrodynamic remediation
148 of heavy metals in soil [13]. Baek K (South Korea)was the most productive author in Asia with 70
149 articles. He analyzed the effect of electrolyte regulation of acidic and alkaline solutions on
150 electroremediation of contaminated soil [14].

151

152 **Journals performance**

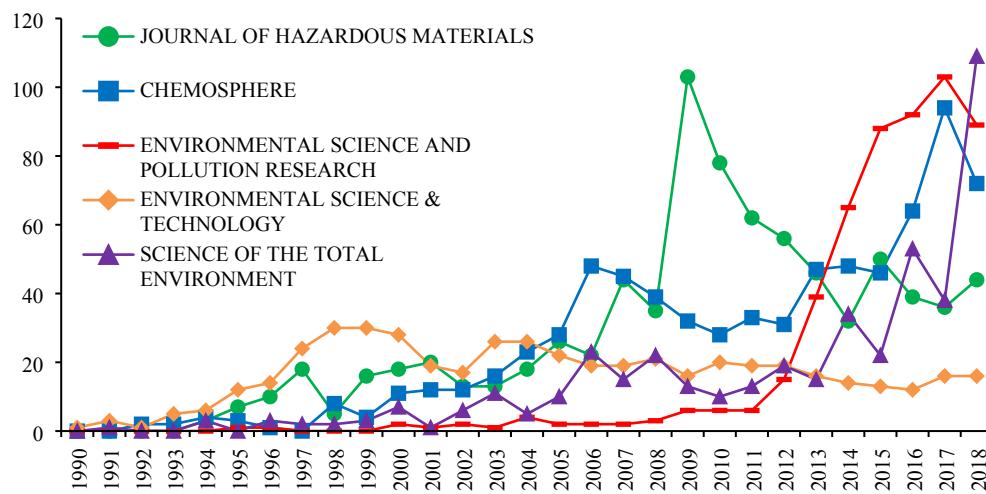
153 1423 academic journals retrieved in the soil remediation field. These articles related to
154 environmental science , soil contamination and botany. Journal of hazardous materials had 822
155 articles (5.9%)was the most published journal (**Table 3**).Chemosphere had 758 articles (5.5%) was
156 the second most published journal. Environmental science and technology ranked fourth among all
157 publications in all journals, however it has the largest impact factor (6.653) and had the most
158 citations (27199).

159 **Table 3 Top fifteen productive journals during 1998-2018.**

Rank	Journal	TP	TPR(%)	IF	TC
1	Journal of hazardous materials	822	5.92	6.434	24491
2	Chemosphere	758	5.46	4.427	21607
3	Environmental science and pollution research	529	3.81	2.8	3985
4	Environmental science technology	482	3.47	6.653	27199
5	Science of the total environment	400	2.88	4.61	9032
6	Water air and soil pollution	369	2.66	1.769	5574
7	Environmental pollution	303	2.18	4.358	12079
8	International journal of phytoremediation	239	1.70	4.005	3371
9	Journal of environmental management	223	1.61	1.886	2592
10	Journal of contaminant hydrology	206	1.48	2.405	7230

160 Note: TP is the number of total articles; TPR(%) is the ratio of the number of journal's publications

161 to the total number of articles; IF is impact factor in 2018;TC is the number of total citations.
162 Among the top five journals, Journal of hazardous materials maintained a leading position in the
163 number of articles from 2008 to 2013 (**Fig 3**). However, the number of articles in Environmental
164 science and pollution research showed a rapid growth with an average growth rate of 30% per year
165 after 2013. Science of the total environment showed short-term fluctuations but maintained high
166 growth rate after 2013. Meanwhile, Journals related to this field from other journals showed
167 relatively low growth rates.



168
169 **Figure 3 Trend of top five journals**

170

171 **Subjects performance**

172 Lists Environmental sciences ecology was the most popular subject with 8550 articles (61.5%)
173 followed by Engineering and Water resources (29.1% and 11.6%) among the top 10 subjects closely
174 related to the field of soil remediation(**Table 4**). Articles in this field focused on natural science
175 subjects especially environmental science, ecology, geology, and meteorology and few social
176 science subjects such as business and economics. Some domain-specified subjects including

177 chemistry, agriculture, plants, and toxicology also published numerous articles because of their
178 sensitivity to soil remediation.

179 **Table 4 Distribution of subjects during 1988-2018.**

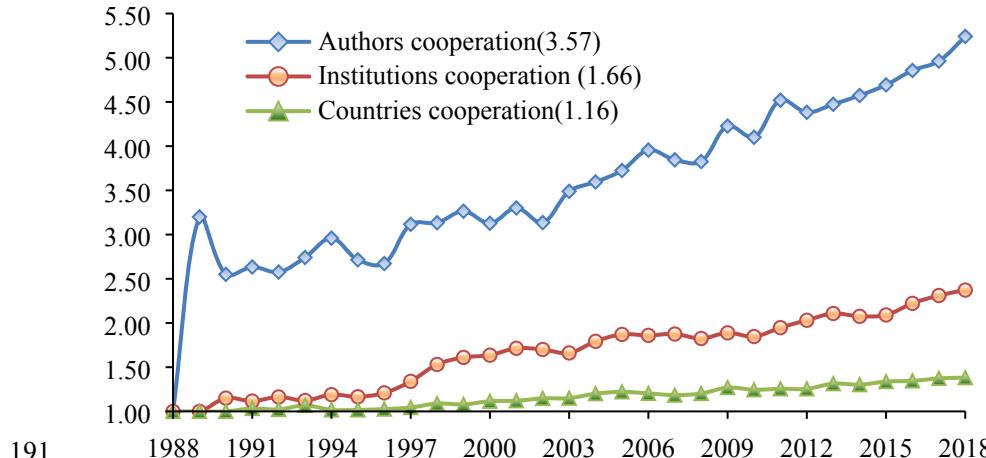
Rank	Subject	TP	TPR(%)
1	Environmental sciences ecology	8550	61.5%
2	Engineering	1043	29.1%
3	Water resources	1612	11.6%
4	Agriculture	1348	9.7%
5	Chemistry	1176	8.4%
6	Geology	863	6.2%
7	Biotechnology applied microbiology	781	5.6%
8	Meteorology atmospheric sciences	434	3.1%
9	Science technology other topics	433	3.1%
10	Toxicology	404	2.9%

180 Note: TP is the number of total articles; TPR(%) is the ratio of the number of journal's publications
181 to the total number of articles.

182

183 **Academic collaboration**

184 The degree of academic cooperation reflects the degree of academic research in scientific research in
185 this field. The degree of cooperation between authors, institutions, and countries was calculated
186 using formulae (1), (2), and (3). Authors, institutions, and countries had cooperation levels of 3.57,
187 1.66, and 1.16, respectively, which indicate that 3.57 authors, 1.66 institutions, and 1.16 countries
188 contributed to each article (Fig 4). The level of cooperation constantly improved, and the authors'
189 cooperation was significant (3.57). Growth in national cooperation was slow due to the soil
190 contamination problems are more concentrated in individual countries.



191
192 **Figure 4 Academic cooperation during 1988-2018**

193

194 **Research hot points**

195 **Keyword clustering and frequency analysis**

196 Keywords reflect the aim of research and summarize the key contents of the paper. We analyzed
197 1039 keywords used in 13891 articles through BibExcel. The keyword “remediation” demonstrated
198 the highest frequency of occurrence (4372 times). According to the formula $n = 0.749 \times \sqrt{m_{max}}$ where
199 $m_{max} = 4372$. In this study, $n=50$ implies that the keywords which are cited more than 50 times are the
200 core of the soil remediation field. We further classified 63 core keywords into 5 categories and
201 labeled the number of occurrence for each keyword (**Table 5**).

202 **Table 5 Frequency of keywords in soil remediation during 1988-2018.**

Category	Representative keywords	frequency
Inorganic pollution	Heavy metals(816),Cadmium(300),Heavy metal(273),Arsenic(270),Lead(261),Metals(141),Chromium(133),Copper(129),Zinc(104),Toxicity(96),mercury(92),Salinity(76),Persulfate(57),Phytotoxicity(57),Nickel(55),Uranium(55),Hexavalent chromium(54),Acid mine drainage(53)	3022
Bioremediation technology	Phytoremediation(719),Bioremediation(633),Biodegradation(347),Biochar(262),Bioavailability(223),Bioaugmentation(115),biosurfactant(106),Bacteria(62),Microbial community(59),Bioaccumulation(59)	2585

Physical remediation technology	Soil washing(223),Adsorption(202),Electrokinetic remediation(181),Sorption(166), Immobilization(161),Electrokinetics(129),Desorption(117), Leaching(107),Electrokinetic(102),Remote sensing(76),Kinetics(71), Stabilization(61),Activated carbon(56)	1712
Organic pollution	Polycyclic aromatic hydrocarbons(162),PAHs(160),phenanthrene(110),PAH(88), Petroleum hydrocarbons(85),Hydrocarbons(81),Crude oil(69),Pyrene(65), Petroleum(57),Polycyclic aromatic hydrocarbons (PAHs)(50),Diesel(50)	1139
Chemical remediation technology	Surfactant(156),EDTA(136),Sequential extraction(98),Surfactants(69), extraction(69),Chemical oxidation(63),pH(55), Hydrogen peroxide(53),Oxidation(53),zero-valent iron(51),citric acid(51)	1056

203 **Inorganic pollution**

204 Heavy metals entered the soil with the rapid development of the global economy. Anthropogenic
205 activities such as mining, industrial production, agriculture, and transportation are the major sources
206 of heavy metals in soil. They cannot be completely removed from the soil by degradation and has
207 caused soil contamination problems in many countries [15]. So “heavy metal” was a prominent
208 keyword in soil contamination. Cadmium, arsenic, lead, chromium, and zinc have been the focus of
209 remediation research followed by toxicity and salinization [16].

210 **Bioremediation remediation technology**

211 Bioremediation uses plants, animals, and microorganisms in the soil to absorb, degrade, and
212 transform the soil Contaminants. “Phytoremediation” and “bioremediation” have been the focus of
213 scholars after 2010 [17]. Bioremediation degrades Contaminants in situ at a low cost of remediation
214 and with no secondary pollution. Due to the limitations of single remediation techniques, joint
215 remediation techniques such as co-bioremediation remediation, physical-biological remediation, and
216 chemical-biological remediation have been considered by some scholars.

217 **Physical remediation technology**

218 In situ soil washing, adsorption, immobilization, and other electric methods are the most studied
219 physical methods [18]. Soil washing remediation mainly improves extraction efficiency by finding
220 new eluents. Electrokinetic remediation was the most concerned chemical remediation technologys.

221 In addition to new electrode technology which was represented by electrolyte optimization and
222 approaching anode, Combined technology was represented by electric-permeable wall began to
223 appeared and developed rapidly.

224 **Organic pollution**

225 Currently, more attention is paid polycyclic aromatic hydrocarbons, tocrude oils and petroleum
226 hydrocarbons in organic pollution [19]. Pollution form Atrazine, chlorpyrifos and
227 dichlorodiphenyltrichloroethane were maily in China, and explosive chemicals were mainly in the
228 USA. With the increasing consumption of US military explosives, greatly studied researched on the
229 soil organic pollution of military bases. China, India, Spain, and Canada foured on the topic of
230 petroleum, crude oil, and Petroleum hydrocarbons.

231 **Chemical remediation technology**

232 The main research in the field of chemical remediation technology was based on the chemical
233 properties of pollutants or contaminated media. This method changed the chemical properties by the
234 application of various chemical reagents, and separates the pollutants. Surfactants solubilize and
235 elute soil contaminants, and EDTA complexes with the salts of heavy metals and increase the
236 transport rate of heavy metals in soil. Thus, surfactants and EDTA were the most concerned
237 chemical remediation technologys [4].

238

239 Co-occurrence and network analysis of keywords

240 Co-occurrence analysis of high frequency keywords was performed using VOSviewer. The common
241 keyword “remediation” was deleted in case it affected the display of other keywords.

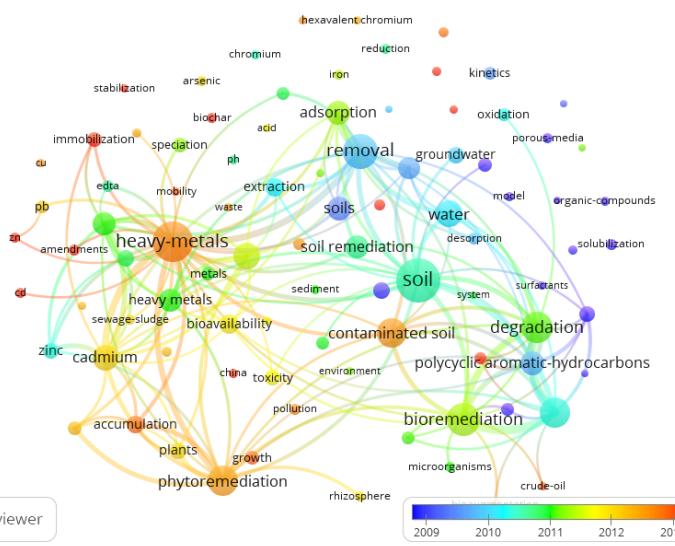


Figure 5 Co-occurrence map of keywords in the field of soil remediation

244 Each keyword is represented by a circle in the visualization result of keyword average time
245 distribution (Fig 5). The diameter of the circle and the size of the label indicate the appearance of
246 keywords. The bigger the circle, the more the number of occurrences of the keyword [20]. The
247 distance between the circles indicates the proximity of the two keywords. The color of the circle
248 represents the average publication year of the keywords. Lines represent co-occurrence links
249 between two keywords. The thicker the line between two keywords, the more frequently they appear
250 together.

251 Heavy metals have more links to other keywords. This means that heavy metals have the maximum
252 connection and reflects its central position in research. Large-scale keywords such as
253 “bioremediation”, “phytoremediation”, and “removal” play an important role in the research

254 network. Among all these keywords, the number of connections between “heavy metals”,
255 “cadmium”, and “removal” was the most. This indicates their relevance and these three keywords or
256 two of them usually appear together in the same research and most scholars focused on these issues.
257 Another keyword group including “phytoremediation”, “bioremediation”, and “contaminated soil”
258 also showed strong correlation, which indicates their relevance in soil remediation research.
259 Change in color indicates the trend in hot topics in this field. Blue represents the keywords that were
260 released before 2009, such as “removal”, “grandwater”, “polycyclic aromatic-hydrocarbons” and
261 “phenanthrene”. These words focused on PAH pollution and the migration mechanism of
262 contaminants in soil. Green represents the keywords around 2011. Increase in soil contamination
263 threatens the living environment and food security. Therefore, scholars have been paying more
264 attention to soil contamination and remediation. The research techniques used were mainly
265 bioremediation technologies including phytoremediation. As an important source of soil
266 contamination, heavy metals continue to receive widespread attention. Studies have focused on
267 “biochar”, “China”, “sewage”, and other specific topics and regions since 2013, rather than abstract
268 and macro themes. These trends indicate that major research in the field of soil remediation is
269 shifting from a contamination mechanism to technology application.

270

271 **Conclusions**

272 Based on the WOS core database, the overall research development in the field of soil remediation
273 from 1988 to 2018 was analyzed using bibliometric methods.
274 Soil remediation field has developed rapidly since 2008. The continuous increase in number of

275 articles indicates that soil remediation is receiving increasing attention. At the national level, the
276 United States had high overall strength with the largest number of articles and greater academic
277 influence. As a representative of developing countries, China's institutions and authors performed
278 well by contributing more number of articles. The top five most published journals contributed 21.5%
279 of all articles in the field in which Journal of hazardous materials was the most published journal. In
280 addition, soil remediation included multidisciplinary fields, and environmental science ecology,
281 engineering, and water resources were the top three subjects that published the most articles. Ottosen
282 LM (Denmark), Reddy KR (the United States) and Baek K (Korea) were the authors with the more
283 number published articles in this field. Academic cooperation showed an increasing trend at the
284 author, institutional, and national levels with an average level of cooperation of 3.57, 1.66, and 1.16,
285 respectively.

286 Cluster analysis and frequency analysis of the keywords indicate that the hot topics in this field were
287 heavy metals, phytoremediation, bioremediation, electrodynamics, cadmium, leaching, solidification,
288 and polycyclic aromatic hydrocarbons. According to the co-word analysis, "heavy metals" keyword
289 had the maximum connection among all keywords and often appeared simultaneously with other
290 keywords reflecting heavy metals as the core issue in the field. Trends in the hot topics in this field
291 were discussed through the analysis of the keywords in published works. We found that research
292 focus is shifting from the mechanism of pollutant transport in contaminated soils to the application
293 of comprehensive repair technologies such as bioremediation technology and electric remediation.
294 Meanwhile, research focused on specific micro-level issues and quantitative analysis in areas and
295 regions. This study will help researchers understand the development trends in soil remediation
296 research and provide guidance for future research.

297 However, this study only explores the overall theme changes of soil remediation research in the past
298 30 years from the time dimension. In order to further analyze the mature and declining process of
299 prominent keywords, it is necessary to further classify and analyze the keywords on a case-by-case
300 basis and summarize the development and decline process of keywords.

301

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306

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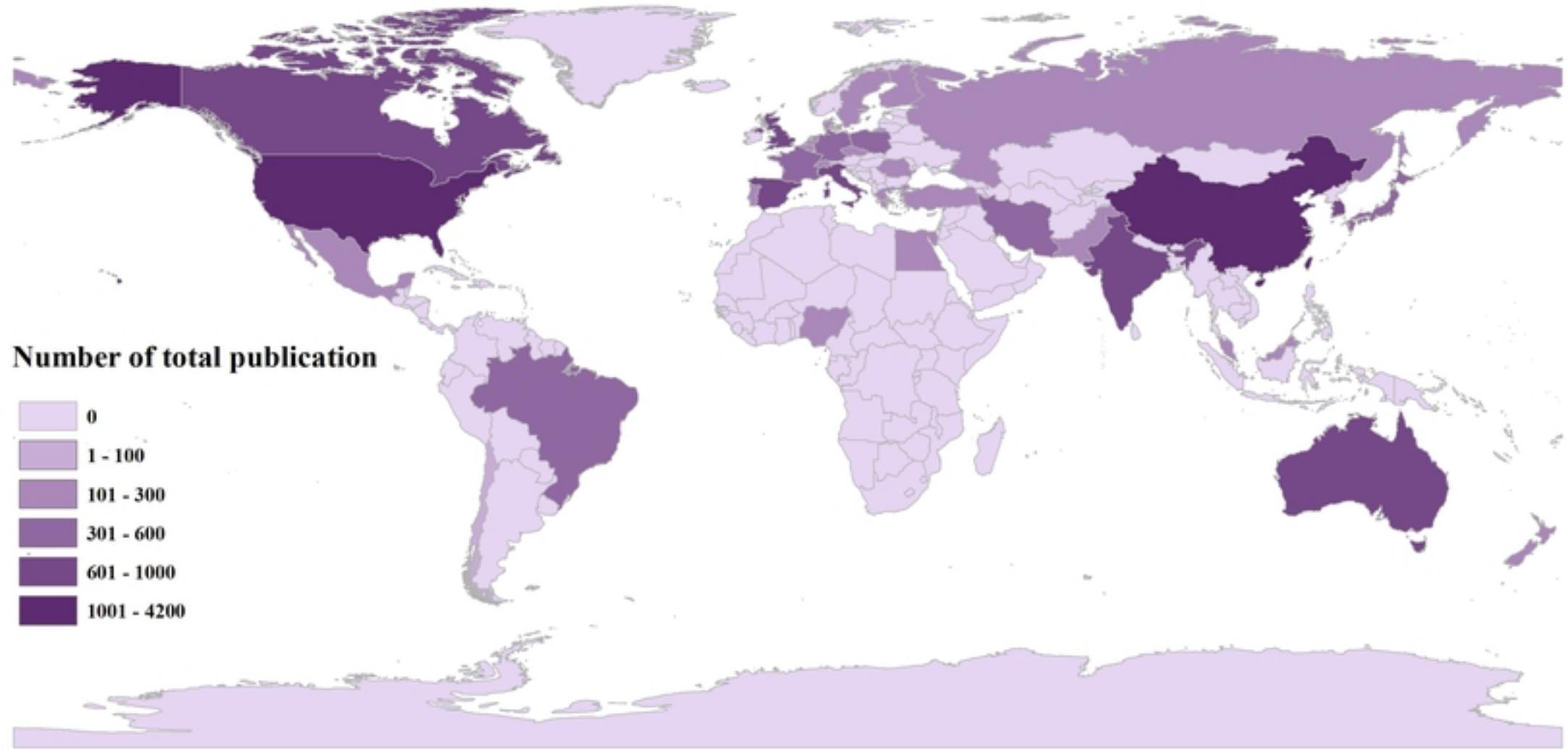


Figure 1

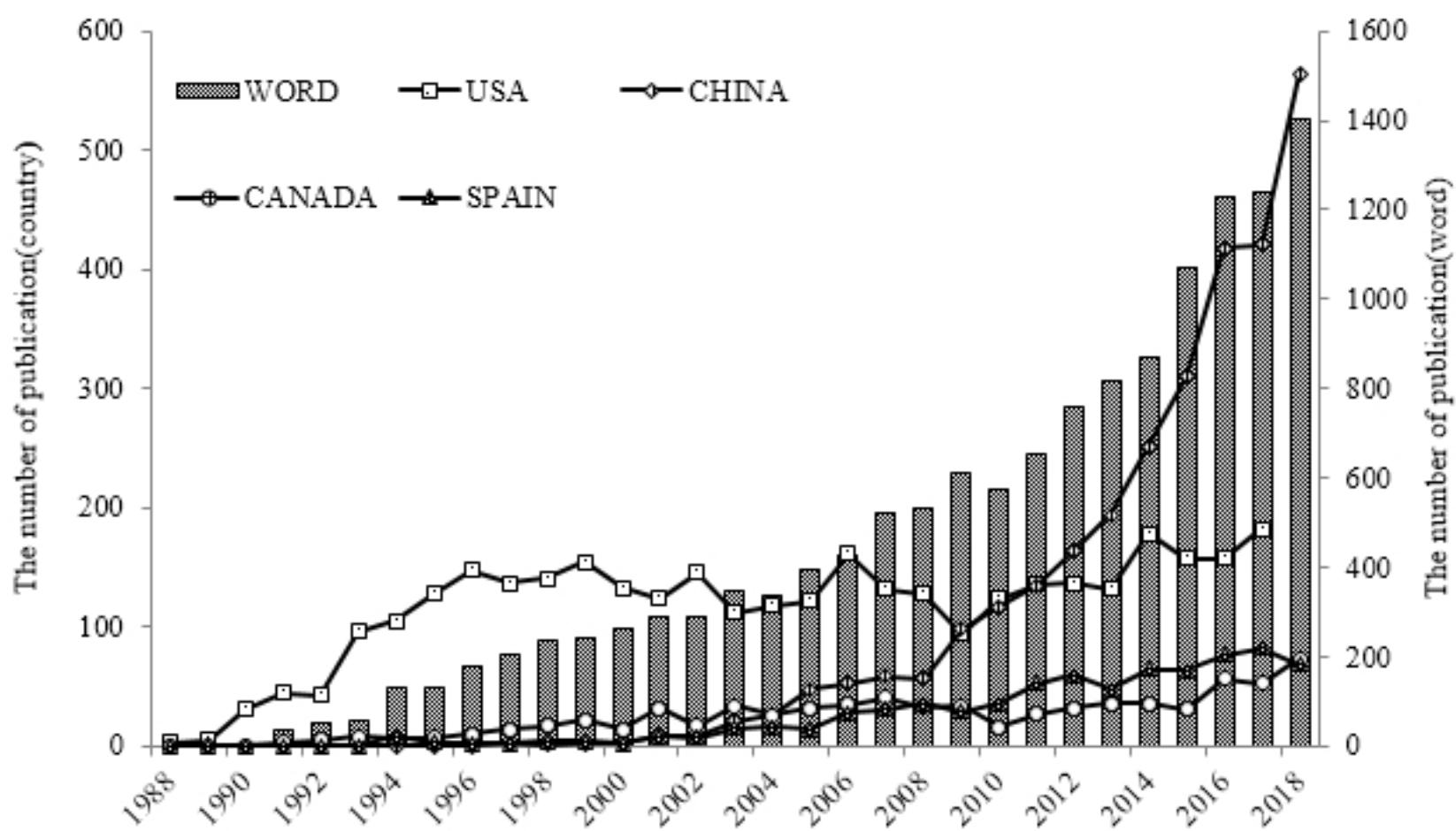


Figure 2

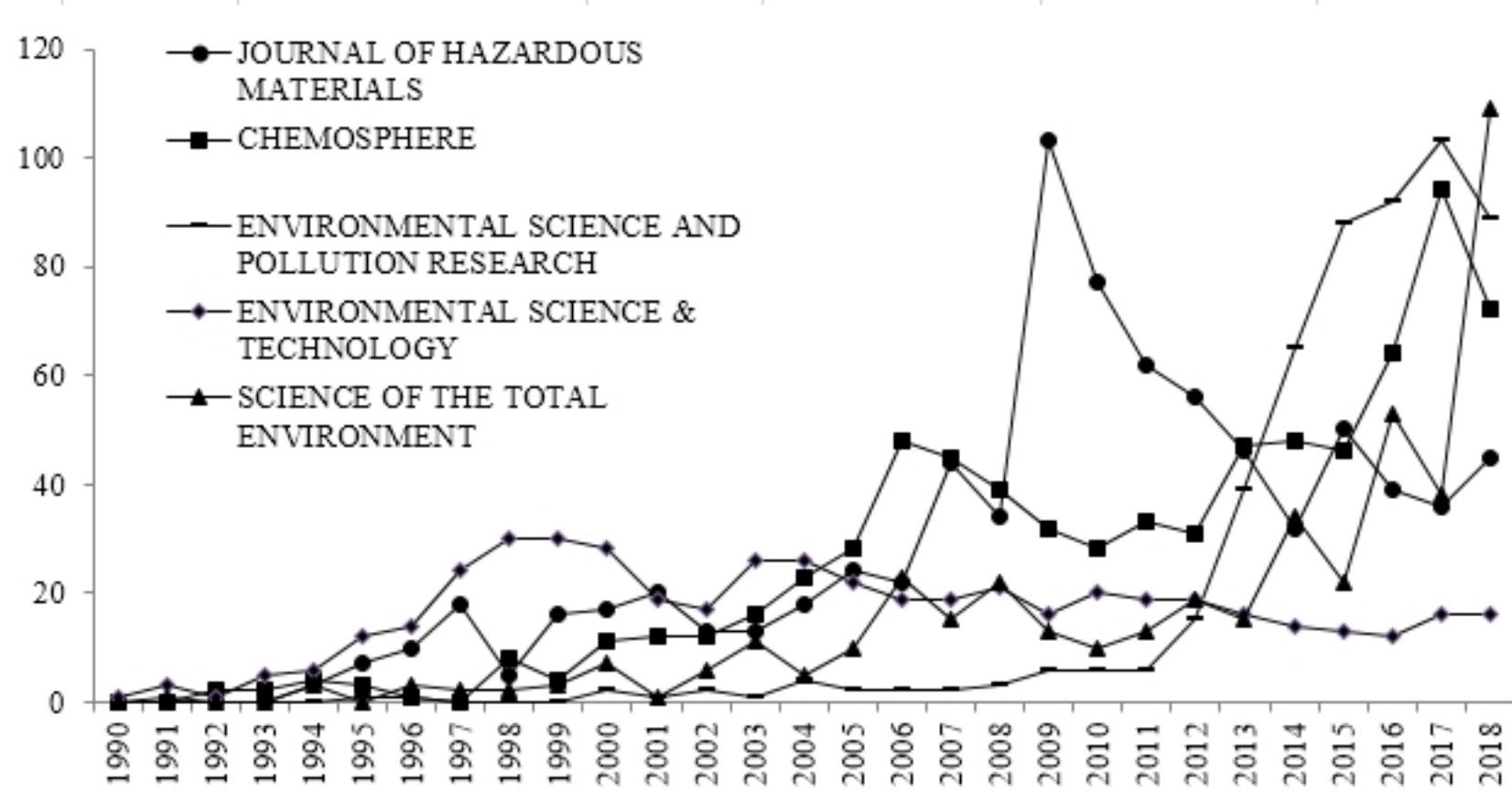


Figure 3



Figure 4

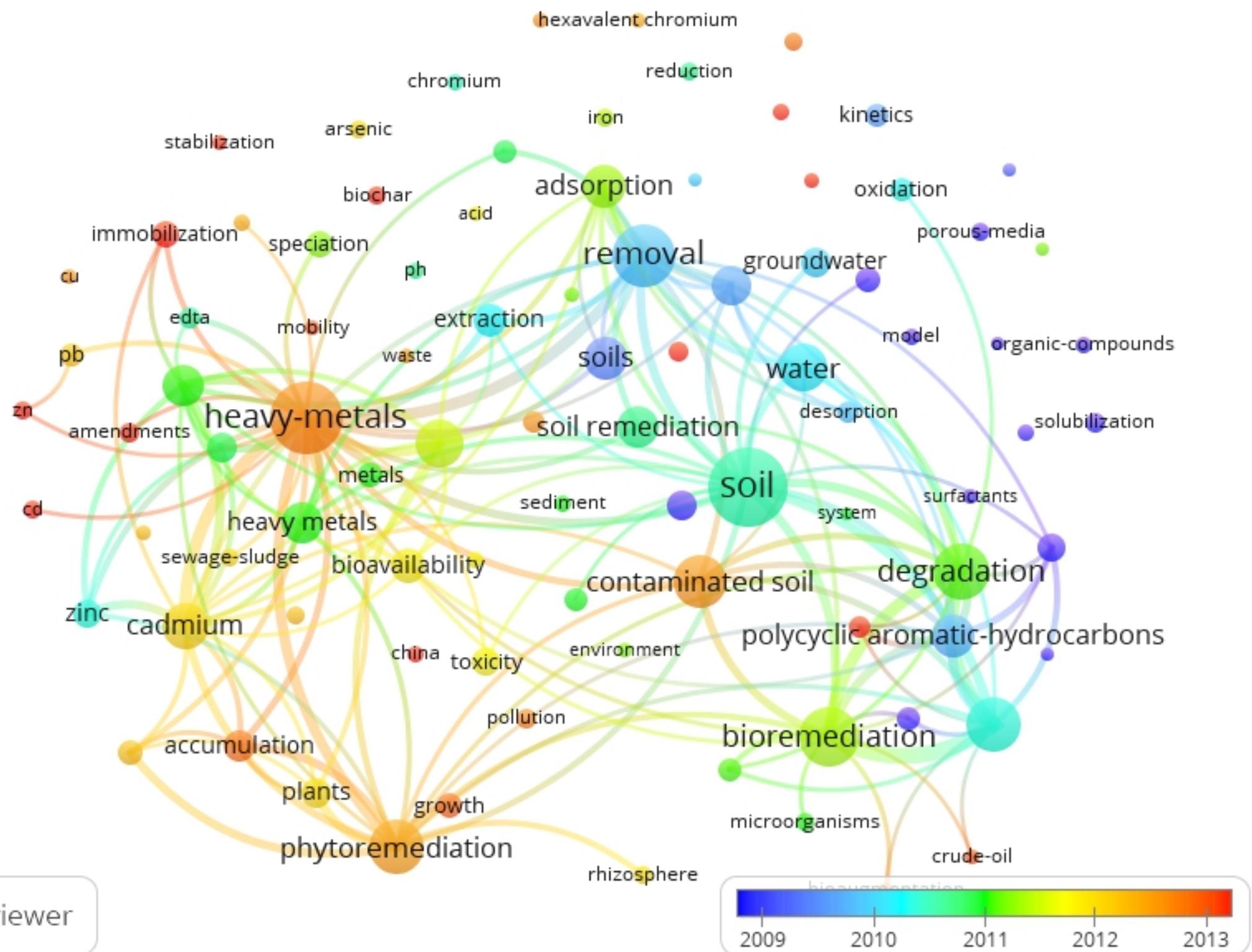


Figure 5